EULAG simulations of orographic banner clouds

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Banner clouds occur downwind of steep mountains or sharp ridges, even on otherwise cloudfree days. Systematic observations at Mount Zugspitze have shown that they can be a rather frequent phenomenon and occasionally persist for several hours. Key scientific questions are the origin of the windward-leeward asymmetry, the underlying basic mechanism, the role of diabatic processes, the role of stratification, and the impact of the mountain shape. Despite many decades of active research in mountain meteorology, the processes and spatial scales relevant for banner cloud dynamics have not recieved particular attention in the past.

This contribution presents simulations of banner clouds using EULAG in LES mode with idealized, but very steep orography. The model setup includes inflow-outflow boundaries in the streamwise direction, periodic boundaries in the spanwise direction, and a damping layer underneath the upper boundary in order to absorb internal gravity waves. The inflow profile represents a stably stratified free atmosphere on top of a deep, neutrally stratified boundary layer. The orography is implemented using the immersed boundaries option of the EULAG model. Key diagnostic is the Lagrangian vertical displacement both on the windward and the leeward side of the mountain. Large upward displacement increases the likelihood for cloud formation.

For a steep, isolated (pyramid-shaped) mountain one obtains a pronounced windward-leeward asymmetry with larger upward displacement on the leeward side. The large leeward upward displacement is associated with boundary layer separation and a rather complex lee-vortex geometry. It follows that banner clouds can be entirely due to orographic dynamics and that moisture asymmetries are not essential. The asymmetry in vertical displacement is lost and even reversed when the mountain becomes more ridge-shaped with the flow becoming increasingly two-dimensional. In that case "flow around the mountain" is replaced by "flow over the mountain" and gravity waves start to play a more dominant role. We also observe flow conditions which are more conducive to cap clouds than to banner clouds. These two cloud types can be distinguished from each other (amongst others) with the help of trajectories: banner clouds primarily consist of air parcels which go around the mountain and experience vertical lift on the leeward side.